Statement of
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NASA's Mission to understand and protect our home planet, to explore the Universe and search for life, and to inspire the next generation of explorers requires that we make strategic investments in technologies that will transform our capability to explore the Solar System. Within the Space Science Enterprise, we are developing the tools, insights, and abilities necessary to answer some of humanity's most profound questions: How did the Universe begin and evolve? How did we get here? Where are we going? Are we alone?

NASA began attempting to answer such questions back in 1962, when we launched the Mariner 1 and 2 missions to Venus. These were the first missions to escape Earth's gravity and explore another planet in our Solar System. At that time, NASA depended on chemical rockets to send spacecraft on their journeys. In order to escape Earth's velocity, a chemical rocket expends all of its thrust within the first few minutes after launch. Once the fuel is expended, the rocket is jettisoned, and the spacecraft begins its expedition by coasting along a fixed path to its final destination in space. Occasionally, there is an opportunity for the spacecraft to swing around another planet to change its direction and velocity. This maneuver – called a gravity assist – is highly dependent upon launching during a specific, and often very short, launch window. Once that window "closes," the time and energy it takes to reach the target destination can change dramatically.

While these launch scenarios have worked well and have allowed us to explore many destinations in our Solar System, the constraints they presented over 40 years ago are still evident today. To overcome these limitations, NASA has begun an aggressive pursuit of alternatives to enhance our capability for launching missions to Solar System objects.

In October 1998, NASA launched Deep Space 1 (DS-1), the first technology-demonstration mission under the New Millennium Program. Not only was the spacecraft developed and launched in just three years, it also demonstrated a number of advanced technologies. DS-1 was the first NASA spacecraft to utilize an electric propulsion system. This system uses electric power to ionize a propellant, like xenon, which is then accelerated through an electric field and expelled to propel the spacecraft forward. The highly efficient ion engine enabled DS-1 to perform a series of interplanetary trajectory maneuvers, yet the propellant accounted for only about 20 percent of the total spacecraft mass. In addition, the velocity increased by 10 kilometers per second (360 miles per hour). Performing the same maneuvers with a chemical propulsion system would be impractical because it would require 10 times more propellant than DS-1 could accommodate within mission and launch constraints.

Nine months after launch, DS-1 had successfully tested all 12 of the new technologies on-board. As a bonus, near the end of the primary mission, DS-1 flew by asteroid Braille, where it took images, measured basic physical properties of the asteroid (mineral composition, size, shape, and brightness), and searched for changes in the solar wind to investigate whether Braille had a magnetic field. In late 1999, DS-1's star-tracker ceased operating; however, within a few months, engineers had successfully reconfigured the spacecraft from a distance of 300 million kilometers (185 million miles) and redirected it for an additional extended mission to encounter comet Borrelly. Such flexibility would not have been possible without the use of electric propulsion.

In September 2001, Deep Space 1 passed just 2,171 kilometers (1,349 miles) from the inner icy nucleus of comet Borrelly, capturing the highest resolution images ever taken of a comet. The daring fly-by yielded new data and movies of the comet's nucleus that are revolutionizing the study of comets. DS-1 was certainly an "overachiever" in terms of a mission: it not only demonstrated all of the planned technologies (most importantly ion propulsion), it also delivered a wealth of scientific data.

In-Space Propulsion

NASA's In-Space Propulsion (ISP) program invests in advanced propulsion technologies that do not depend on a nuclear fission reactor as the power source. The high-priority technologies in ISP include solar electric propulsion, solar sails, and aerocapture. System analysis trade studies have quantified the benefits of these technologies for a wide variety of challenging potential future missions. ISP is also making smaller investments in other technologies, including advanced chemical propulsion, plasma sails, momentum exchange electrodynamic reuse tethers, solar thermal propulsion, and ultra-lightweight solar sails. The high-priority technologies are focused on achieving readiness within 3-5 years, so that they can be incorporated into space science missions in the not-too-distant future. One critical path for achieving mission implementation is the demonstration of some of the technologies in space prior to being used for a mission. In much the same way that DS-1 served as a technology demonstration for ion propulsion, the ISP program looks to New Millennium Program missions as the means for future flight demonstrations of high-priority technologies, such as aerocapture and solar sails.

Future Solar System exploration missions will have diverse requirements depending on their specific scientific objectives; therefore, it is important that we develop a variety of new technologies to support them. Simply put, certain propulsion systems are better suited to particular missions than others. For example, there is a class of missions supporting the Sun-Earth Connection science theme that involves positioning advanced monitoring spacecraft in the Sun-Earth line at a location that requires constant thrust to maintain position. Independent studies have found that a solar sail propulsion system is optimal for this application of continuous low thrust, without the need for propellant. Other missions to explore planetary bodies could benefit from solar-electric propulsion, similar to that used by DS-1. With new investments being made to dramatically improve efficiency, we expect an even more impressive “second generation” ion system, which will be ready before the end of the decade. Other missions may require inserting a spacecraft into orbit around a planet or a moon, such as Titan. In cases where the planet has an atmosphere, the advanced propulsion technique called aerocapture has shown significant mission-enabling promise. Aerocapture uses drag forces generated during a spacecraft’s passage through a planet’s atmosphere to slow it down enough to go into orbit around that body without consuming large quantities of fuel. For missions of limited scale, with objectives at a single planet, this technique offers significant efficiencies over conventional propulsion systems.

ISP is a technology development program that operates on the basis of competition among technology providers; approximately three quarters of the program’s budget is dedicated to competitive procurements. The competition is open to industry, academia, and government laboratories, including NASA Centers. The Program uses rigorous mission and system analyses to establish the metrics and processes for determining which technologies are worthy of investment. Clear alignment with NASA Space Science Strategic goals is critical, and technology investments must be demonstrably linked to the achievement of science goals and missions in the NASA Space Science Strategic Plan.

<u>Project Prometheus</u>

In the words of Nobel Prize winner Marie Curie “ . . . never see what has been done . . . only see what remains to be done.” In the field of space exploration, this translates to constantly striving to find more effective ways to safely power, propel, and maneuver spacecraft, while developing innovative scientific instruments to explore the worlds beyond our current reach.

Achievement of this ambitious vision requires a bold approach to the next generation of spacecraft, including revolutionary improvements in energy production, conversion, and utilization. NASA will inspire this bold undertaking through Project Prometheus (the nuclear systems program), which will develop the near- and long-term use of nuclear energy to power scientific missions. At present, we are pushing the limits of innovation with solar and chemical power. It is only by harnessing the tremendous energy within the atom that we can aspire to fundamentally improve our capability for Solar System exploration and enable missions of greater longevity, flexibility, and, therefore, significantly improved scientific return. Beyond robotic exploration, NASA foresees that Project Prometheus could ultimately serve as humankind's pathway to the outer reaches of the Solar System.

At the heart of this undertaking is the wonder of the atom – specifically, making use of the heat produced by the natural decay of a radioisotope and tapping that heat to provide electricity. That electricity can then be used to power the instruments aboard the spacecraft, as well as to propel the spacecraft forward.

On January 16, 1959, President Eisenhower unveiled "the world's first atomic battery" -- the radioisotope thermoelectric generator (RTG). While not actually batteries, these amazing devices have become NASA's energy source for missions to the outer planets; they have proven to be rugged, compact, and capable of working in severe, sunless environments. NASA plans to ensure their availability for future missions by regenerating the Nation's capability to build radioisotope power systems (RPS, which includes RTGs) to support the safe and peaceful exploration of space and the surfaces of planets and moons.

The importance of the radioisotope power system's contribution to NASA's exploration beyond Earth orbit is often overlooked. To date, radioisotope systems have flown on 19 NASA missions. They provided electricity, during lunar day and night, to five Apollo Lunar Surface Experimental Packages. They powered the two Viking Landers while they conducted research on the surface of Mars and heated the Mars Pathfinder Lander and its rover, Sojourner, during the frigid Martian nights. They also powered the Pioneer and Voyager interplanetary missions as they explored the outer Solar System. Amazingly, Voyagers 1 and 2 continue to operate today, after more than 25 years in space, exploring the outer frontiers of our Solar System. Radioisotope power sources are currently powering the Ulysses spacecraft as it voyages around the Sun's poles, and the Galileo and Cassini spacecraft both use radioisotope power systems to study the Jupiter and Saturn systems, respectively (Cassini will arrive at Saturn in July 2004).

Because of the utility of these "behind-the-scenes players," it is incumbent upon NASA not only to make current radioisotope power systems more efficient, but also to develop the next generation of such systems. For example, the 2009 Mars Science Laboratory (MSL) mission has been baselined to accommodate either an RTG or its possible successor, the more efficient but less mature Stirling Radioisotope Generator (SRG). Additional missions could also include radioisotope power systems of various power levels, pending the outcome of ongoing, competed mission-of-opportunity proposals.

Radioisotope power systems are limited to providing spacecraft with tens to hundreds of watts of power. To the average citizen, this would seem like a ludicrously small amount of power (akin to several household light bulbs) for an entire spacecraft; however, the ingenuity of the science and engineering communities have adapted mission plans to this present reality and developed spacecraft and instruments capable of utilizing these small amounts of power. Although we can envision many future space applications that might require this range of power, for exploration at the outer reaches of the Solar System this is a significantly limiting factor on our ability to gather data and, ultimately, to generate knowledge.

The truly revolutionary aspect of Project Prometheus rests in its ability to provide orders of magnitude more power – thousands to hundreds of thousands of watts – to spacecraft in the cold dark outer Solar System, or the vastness of interstellar space. The amount of energy generated represents a true paradigm shift for mission planners, not only because of the unprecedented amounts of power available to the scientific community, but in the ability to provide continuous power to maneuver a spacecraft throughout its mission via nuclear electric propulsion.

In simple terms, nuclear fission provides the high levels of sustained energy necessary to power more complex, “active” scientific instruments, allow a spacecraft to visit multiple destinations per mission, and enable significantly larger amounts of data to be transmitted back to Earth.

Whereas space chemical propulsion is the “drag racer,” rocketing straight ahead at high speeds in a matter of seconds, the nuclear-electric-propelled spacecraft is more like a 4-cylinder car that is capable of efficiently using its fuel for an extended period of time during a tour of the United States. To take this analogy further, even though the nuclear-electric spacecraft would start well behind its chemical partner, in time it would overtake and speed past its coasting counterpart. In addition, nuclear-electric-propelled spacecraft will afford us the opportunity to dictate new ground rules for observation and, as such, we will be rewarded with days, weeks or even months of up-close observations of single or multiple targets.

Moreover, the spacecraft acceleration and course-change capability offered by nuclear-electric propulsion would also open up new launch opportunities. We are currently severely limited by the ‘geometry’ of the Solar System; that is, chemically propelled planetary missions can launch only during limited periods when the relative positions of the planets will allow a spacecraft from Earth to reach a particular destination.

These capabilities, however, are not an end unto themselves. Rather, Project Prometheus will leverage the extensive work done to date on space nuclear systems to embark on an ambitious science mission, the Jupiter Icy Moons

Orbiter (JIMO), which will be enabled by nuclear fission electric power and propulsion. At the same time, JIMO will respond to the National Academy of Sciences' ranking of a Europa orbiter mission as the number one priority for a flagship Solar System exploration mission

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Because of the unprecedented capabilities made possible by space nuclear power, NASA will be able to go well beyond the Academy's recommendation. JIMO's nuclear-electric propulsion will provide the maneuverability to orbit all three of Jupiter's icy Galilean moons and respond to new discoveries, an impossible feat under the current technology paradigm. This will allow months of scientific investigation at these destinations that will far surpass the brief fly-bys made by Galileo and Voyager. The science instruments used to study these worlds will have far more power than those on Galileo and Voyager. Options for new instruments include high-power radars to probe the subsurfaces of the moons looking for oceans that could harbor life. More powerful cameras and spectrometers could document the entire globe looking for evidence of this life, and lasers could measure the topography and characteristics of the surface. Unlike previous missions, the power available on the spacecraft will allow all of the instruments to be operated simultaneously throughout the mission. Increased mission time will allow JIMO to investigate the entire surface of a given moon and look for any changes due to new geysers or other eruptive activity. This activity could bring fresh material from underground oceans to the surface – material that could contain evidence for life. The huge amounts of data gathered by JIMO will be transmitted to Earth in torrents, using high-powered transmitters and optical communication links.

Looking beyond JIMO, future missions making use of nuclear systems might visit destinations such as:

- Comets: to explore their surfaces and interiors and return samples to better understand the building blocks of the Universe.
- Mars: to dramatically expand our capabilities for surface, on-orbit exploration, and sample return.
- Various other destinations: interplanetary or interstellar probes to study Saturn, Uranus and Neptune, or investigate the interstellar matter beyond the Kuiper Belt region.

Project Prometheus will enable the fulfillment of many of NASA's most challenging scientific goals, as well as our ability to answer some of life's most intriguing questions: Is there life elsewhere in the Solar System? How was the Solar System formed and what is its future? Our pursuit of answers to these questions will be greatly enhanced when we are able to explore space in a manner fully under our control and using state-of-the-art science instruments.

Although accessing such energy resources in space will be a boon to robotic missions, Project Prometheus may have its most compelling long-term impact in expanding the capability of humans in space and perhaps one day serving as our pathway to the outer Solar System.

Use of nuclear and other advanced technologies involves certain risks and responsibilities. In all of NASA's missions, safety is the primary operating principle, and this has always been the case with our nuclear activities in particular. Historically, the United States has demonstrated an excellent record of safely using nuclear power in space exploration. NASA has over 30 years' experience in the successful management and operation of radioisotope power systems. Working with the Department of Energy, the agency responsible for development and production of nuclear technologies, NASA will extend that safety experience to the design, manufacture, and space flight of a fission reactor. NASA will continue to engage and solicit expertise in risk management and risk assessment and will fully comply with environmental and nuclear safety launch approval processes applicable to the use of nuclear power systems in outer space. Safety must continue to be the predominant factor as we explore the Universe and attempt to unlock the many secrets it holds.

This is an exciting time for space science. We are standing at the threshold of a new era in space exploration. There is a renewed sense of excitement and anticipation that the future holds great things for NASA. Our efforts to improve propulsion and power capabilities are a major reason for this optimism. I will conclude my remarks by noting one of the major findings of the recent Commission on the U.S. Aerospace Industry, which concluded that space power and propulsion are the key technologies that will enable " . . . new opportunities on Earth and open the Solar System to robotic and human exploration . . ." .